

Technical Assistance for Developing Effective Plastic Waste Management System, A Review

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Abstract— To establish an effective plastic waste management system, it is indispensable to know the actual waste stream of plastic waste. It is also noted that there are various types of plastic waste materials, and the technologies of pretreatment, recycling, and final disposal differ depending on the type. Plastic material recycling becomes possible through mechanical, thermal, and chemical methods, and sorting plastic waste by type and pre-treating, such as washing, crushing, etc. are required. The plastic waste management system depends on not only technologies and infrastructure, but also institutional setting including economic instruments and public awareness on the issue. In the institutional setting, it is necessary to consider the basic concepts both Polluter Pay Principle (PPP) and Extended Producer Responsibility (EPR). It is necessary to effectively apply legal systems, regulations, and standards regarding plastic waste, as well as policies that promote the active use of recycled plastic materials. In this paper, the methods and challenges for developing effective plastic waste management systems are reviewed and discussed.

Keywords— Plastic waste management, 3R, Extended producer responsibility (EPR), Marine plastic pollution

I. Introduction

Since the 1950s, plastic has become a material that has spread widely in human society with the development of the petrochemical industry. It is lighter than other materials, easy to mold, has excellent physical properties such as flexibility, water resistance, electrical insulation, transparency, and low cost by mass-production. It is estimated that over 300 million tons (Mt) of plastic waste is produced annually for use in a wide variety of applications [1]. Today, plastics are essential substances not only as raw materials for products but also as packaging materials, where a huge amount of plastic wastes are generated after the consumption over the world.

However, the excellent physical properties mentioned above are also difficult properties from the viewpoint of solid waste treatment and disposal. The lightweight and bulky properties of plastics makes it less financially efficient to collect and transport when they become solid wastes. In addition, when plastic waste is landfilled, it takes up a lot of space and shortens the life of the landfill. It also hinders the stability of landfills because plastics are difficult to decompose and highly water resistant.

According to statistical study using a business-as-usual model [6], the annual amount of mismanaged plastic waste (MPW) has been estimated 60-99 Mt in 2015, while this figure could triple to 155-265 Mt/year by 2060. The future MPW load will continue to be disproportionately high if no effective measure be taken. Inadequately mismanaged plastic waste scatters into the environment and ends up in the ocean, which causes coastal and marine plastics problems [2]. Based on the estimation in 2010 [4], 4.8 to 12.7 Mt of plastic waste entering the oceans in the world, and plastics makes up 80% of all marine debris found from surface waters to deep-sea sediments [1].

Weathering degradation of plastics on the beaches results in their surface embrittlement and microcracking, yielding microparticles that are carried into water by wind. Marine plastics eventually generate micro-plastics through the physical destruction of waves and deterioration of plastic materials by ultraviolet rays, which harms the ecosystem [2, 15]. Moreover, microplastics often concentrate persistent organic pollutants (POPs) by adsorption [17]. Consequently, the microparticles laden with high levels of POPs can be ingested by marine biota [3].

The source of marine plastic is mainly poorly managed solid waste on land or illegally disposed fishery plastic [5, 18], which indicates that the marine plastic problem is mostly caused by an inadequate solid waste management on land. Plastic waste problems are prominent in many developing countries of Global South where solid waste management (SWM) system is not always well established [5]. In this paper, it will be discuss that methods and challenges for solving the plastic waste problems [19], and the way of technical assistance for combatting the plastic waste problems in developing countries of Global South.

II. Methods of Analysis

In order to develop an effective plastic waste management system, the following six analyses and assessments are required;

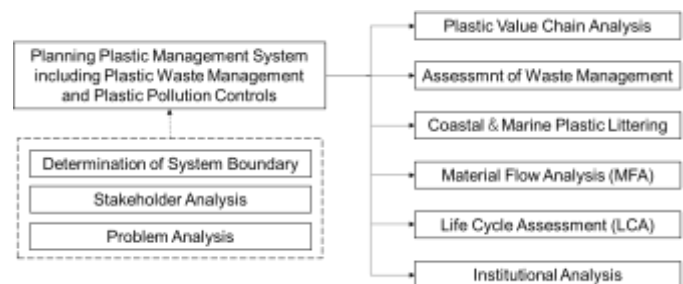


Figure 1. Framework of the planning of plastic waste management

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(A) Plastic Value Chain Analysis, (B) Assessment of Solid Waste Management, (C) Assessment of Coastal and Marine Plastic Littering, (D) Material Flow Analysis, (E) Life Cycle Assessment, and (F) Institutional Analysis (Fig.1).

The determination of system boundary, stakeholder analysis, and problem analysis must be performed, which are prerequisites for any analysis, but not all other analyses from (A) to (F). It can be selected according to the conditions and availability of data.

A. Plastic Value Chain Analysis

To analyze a plastic value chain [14], a comprehensive value chain analysis should be conducted. This type of study involves understanding the entire lifecycle of plastic products, from raw materials to production, distribution, consumption, recycling, and disposal (Fig.2). Key components of a plastic value chain analysis [9] include the following eight actions:

A-1) Plastic value chain stakeholder analysis: Clarify the stakeholders in the plastic value chain, such as raw material producers, manufacturers, suppliers, retailers, consumers, recycling service providers, NGOs, research institutions, and policymakers, to gather their perspectives and identify areas of collaboration or partnership. Group stakeholders based on their roles and level of involvement in the value chain, such as primary (directly involved) and secondary (indirectly involved) stakeholders. Understand the goals, interests, and motivations of each stakeholder group. This may include financial gains, regulatory compliance, environmental concerns, social impact, or reputation management. Determine the level of power and influence each stakeholder has within the plastic value chain. Consider factors such as decision-making authority, access to resources, and the ability to mobilize public opinion. Design tailored engagement strategies to collaborate with key stakeholders, addressing their interests and leveraging their influence. This may involve communication, consultation, partnerships, or joint projects.

A-2) Study on raw materials supply: Assess the sources and types of raw materials used in the production of plastics, such as naphtha, refined materials, and polymer feedstocks. Evaluate the availability, costs, and supply chain of these resources. It is essential to have an understanding of import data and domestic supply of plastic raw materials.

A-3) Study on plastic production processes: The analysis of the plastic production process involves understanding the various stages and techniques involved in transforming raw materials into finished plastic products. Raw materials are processed into monomers including ethylene (C₂H₄), propylene (C₃H₆), and styrene (C₈H₈). The analysis should focus on the efficiency and environmental impact of the processes used to produce monomers, such as steam cracking and catalytic cracking. Monomers are combined to form polymers through a process called polymerization. Analyze the energy consumption, greenhouse gas emissions, and waste generation associated with these processes. Polymers are mixed with additives to achieve desired properties, such as color, strength, or resistance to UV radiation. Polymers are transformed into plastic products using various processing techniques, such as injection molding, blow molding, extrusion, and thermoforming. Assess the energy efficiency, waste generation, and environmental performance of these processes, as well as opportunities for optimization or innovation. Assess the design and innovation trends in the plastic industry, including new materials, production technologies, and product designs that promote sustainability, recyclability, or biodegradability.

A-4) Study on distribution, consumption patterns: Analyze the distribution systems for plastic products, including logistics and reverse-logistic management. Plastic products are packaged, transported, and distributed to consumers. In this stage, evaluate the environmental impact of packaging materials, transportation methods, and the product's lifespan, considering opportunities to reduce waste, extend product life, or promote recycling and reuse. Understand the consumption patterns of plastic products, including the types of products, market segments, and consumer preferences. Assess the environmental and social impacts of plastic consumption.

A-5) Study on end-of-life plastic management and recycling: After use, plastic products are either discarded, recycled, or repurposed. Evaluate the current plastic waste management practices, including collection, transportation, intermediate treatment, recycling, and disposal. Identify opportunities for improving plastic waste reuse, recycle, and recovery rates (see next Section B).

A-7) Problem analysis in plastic value chain: The plastic value chain involves various environmental, social, and economic challenges associated with the production, use, and disposal of plastics. It is required to identify the root causes of these issues, prioritize them, and develop solutions that promote a sustainable and circular plastic economy. List up the key problems and challenges in the plastic value chain, such as plastic pollution, waste management, greenhouse gas emissions, resource depletion, and negative social impacts. Collect relevant data and information to quantify the extent and severity of the identified problems. Use sources such as industry reports, scientific studies, and government statistics to ensure accuracy and reliability. For each problem, investigate the underlying causes and contributing factors. This may

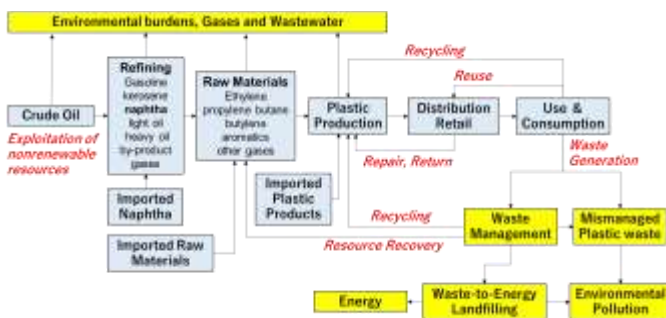


Figure2. Plastic value chain and environmental loads

involve examining the processes, materials, and behaviors at each stage of the plastic value chain, from raw material extraction to waste disposal. Create visual representations of the relationships between the identified problems, their root causes, and contributing factors. This can help better understand the complexity of the issues and identify potential points of intervention. Rank the identified problems based on their severity, urgency, and potential impact. Consider factors such as the scale of the problem, the number of people affected, and the potential for negative long-term consequences. For each prioritized problem, brainstorm potential solutions that address the root causes and contributing factors. Consider a range of approaches, such as technological innovations, policy changes, consumer education, and industry collaboration.

A-6) Economic analysis of plastic value chain: Assess the economic aspects of the plastic value chain, including the costs of production, distribution, and waste management, as well as potential revenue streams from recycling or innovative solutions.

B. *Assessment of Solid Waste Management*

To understand the solid waste management and waste stream (see Fig.4), a comprehensive waste characterization study is conducted as follows:

B-1) Waste generation and composition analysis: Determine the quantity and types of waste generated in the target area, including residential, commercial, institutional, and industrial sources. Assess the generation rate per capita per day (kg/capita/day) and identify trends or seasonal variations. Analyze the waste composition by collecting representative samples from various waste sources [11]. This can help in determining the percentage of recyclable, organic, hazardous, and inert materials in the waste. This analysis will reveal the types and percentages of plastics in the waste.

B-2) Waste collection and transportation: Evaluate the current waste collection and transportation systems, including collection frequency, routes, and the types of vehicles operated. Clarify whether plastic waste is collected separately from sources or sorted from mixed waste collected.

B-3) 3Rs programs in solid waste management: Analyze existing waste reduction and minimization, or 3Rs (Reduce, Reuse, Recycle) [10] policies and programs, including public awareness campaigns, economic instruments, and infrastructure for plastics reuse/recycle. Assess the existing waste management facilities, such as sorting centers, recycling centers, and waste-to-energy (WtE) plants. Evaluate their capacity, operational efficiency, and environmental compliance.

B-4) Financial analysis: Assess the financial sustainability of the solid waste management system in the target area, including costs associated with waste collection,

transportation, and disposal, as well as potential revenue streams from recycling or waste-to-energy initiatives.

B-5) Stakeholder participation and engagement: Engage with various stakeholders, such as local government, waste management service providers, community organizations, and citizens, to gather their perspectives and identify potential areas of collaboration or partnership.

C. *Assessment of Coastal and Marine Plastic Littering*

The microplastic level of different coastal and marine ecosystems nearly ranged from 0.001-140 particles/m³ in water and 0.2-8766 particles/m³ in sediments at different aquatic environments over the world [21]. To assess coastal and marine plastic littering (Fig. 3), a comprehensive study should be conducted as follows:

C-1) Monitoring and data collection survey: Conduct regular surveys and observations along the coast and in the marine environment to quantify the amount, distribution, and types of plastic litter present. This can include beach litter surveys, floating debris surveys, and underwater debris assessments.

C-2) Litter characterization: Analyze the collected litter samples to determine the composition of the plastic debris, including the types of plastic (e.g., PET, HDPE, LDPE), product categories (e.g., packaging, fishing gear, consumer products), and the size and shape of the debris. Observe the littering of plastic debris along coastal zone.

C-3) Source identification: Investigate the potential sources of the plastic litter, such as land-based (e.g., littering, stormwater runoff, wastewater discharge) and ocean-based activities (e.g., shipping, fishing, aquaculture). Evaluate the relative contributions of each source to the overall litter problem. Study the transport pathways and mechanisms of plastic litter in the coastal and marine environment, considering factors such as ocean currents, wind, and tides. Assess the potential for debris to accumulate in specific areas or hotspots.

C-4) Environmental impacts: Evaluate the potential impacts of plastic litter on coastal and marine ecosystems, including entanglement, ingestion, smothering, and habitat degradation. Assess the effects on various species, such as fish, corals, seabirds, marine mammals, invertebrates, and flora.

C-5) Socio-economic impacts: Analyze the socio-economic impacts of plastic litter, including costs related to cleanup efforts, tourism, public health, amenity, and commercial fishing.

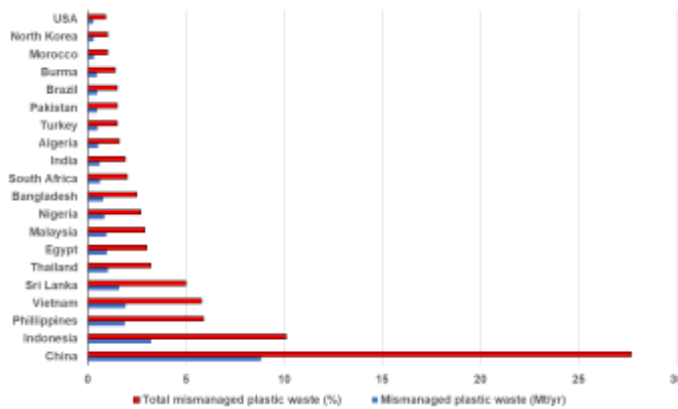


Figure 3. An estimation of top twenty countries for the amount of mismanaged plastic waste (Mt/year) and its global share percentage (%) flowing into oceans (Data source [16]). Most countries are in the Global South.

C-6) Mitigation measures and best practices: Evaluate potential mitigation measures and best practices to reduce coastal and marine plastic litter, if any. These may include plastic waste management improvements, public awareness campaigns, product design changes, bans on single-use plastics (SUP), and enforcement of existing regulations.

C-7) Microplastic analysis: Microplastics are small plastic particles typically less than 5 mm in size. They can be divided into two categories: primary microplastics and secondary microplastics. Primary microplastics are intentionally manufactured small plastic particles. Primary microplastics are used in various applications, such as personal care products (e.g., facial scrubs, cosmetics), industrial abrasives, and others. Secondary microplastics are formed as a result of the degradation of larger plastic items. Microplastics have emerged as a significant environmental concern due to their widespread presence in aquatic and terrestrial ecosystems. To assess marine microplastic pollution, a multidisciplinary study will be conducted.

D. Material Flow Analysis (MFA)

Material Flow Analysis (MFA) is a systematic assessment of the flow of materials within the system boundary. It helps to identify the sources, pathways, and destinations of materials, and to understand the efficiency of resource use and potential environmental impacts. The following steps are the necessary for MFA:

(D-1) Determine the material categories: Categorize the types of plastics targeted, such as single-use plastics, packaging materials, and durable goods. Gather data on the production, consumption, and disposal of plastics within the system. This may involve collecting information from industry reports, government statistics, waste audits, and other sources. Ensure that the data is consistent and compatible with your system boundaries and material categories.

(D-2) Construct a material flow diagram: Create a visual representation of the flow of plastics within the system, using arrows to indicate the direction and magnitude of material

flows. This diagram should include the key stages of the plastic life cycle, such as production, manufacturing, use, disposal, and recycling.

(D-3) Quantify material flows: Calculate the mass of plastics at each stage of the life cycle and the flow rates between stages. This will help for identifying the main sources of plastic waste, the efficiency of recycling processes, and potential areas for improvement in resource management.

(D-4) Identify intervention points: Based on the MFA results, identify opportunities for improving plastic waste management and reducing environmental impacts. These may include promoting waste reduction, enhancing recycling infrastructure, or implementing policy interventions to incentivize sustainable practices. Develop actionable recommendations for stakeholders, based on the MFA findings and intervention points. This may involve suggesting specific waste reduction strategies, policy changes, or technological innovations to improve plastic waste management.

E. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a systematic method used to evaluate the environmental impacts of a product or process throughout its entire life cycle, from raw material extraction to disposal or recycling [20]. When applied to plastics, LCA helps identify the areas where improvements can be made to reduce the environmental footprint. An LCA of plastics typically involves the following stages:

(E-1) Goal and Scope Definition: The first step is to define the purpose of the study, the product or process being assessed, the functional unit (a quantifiable measure of the function of the product, e.g., 1 kg of plastic packaging), and the system boundaries (which stages of the life cycle will be included in the analysis).

(E-2) Life Cycle Inventory (LCI): This stage involves collecting data on the inputs (raw materials, energy, water) and outputs (emissions, waste) for each stage of the plastic's life cycle. The main stages include:

- 1) Raw material extraction: The extraction and processing of raw materials required to produce the plastic, such as petroleum or natural gas for conventional plastics or biomass for bioplastics.
- 2) Production: The manufacturing processes involved in converting the raw materials into plastic resins, additives, and finished products.
- 3) Distribution: The transportation of raw materials, intermediate products, and finished products throughout the supply chain.
- 4) Use and consumption phase: The impacts associated with the use of the plastic product, such as energy consumption, maintenance, or additional resource use.
- 5) Waste phase: The disposal or recovery of the plastic waste, including options like landfilling, incineration, recycling, or composting (for biodegradable plastics).

6) Life Cycle Impact Assessment (LCIA): In this stage, the inventory data is translated into potential environmental impacts using established impact categories and characterization factors. Common impact categories include climate change, eutrophication, acidification, ozone depletion, human toxicity, and resource depletion, among others.

7) Overall interpretation: The results of the LCIA are analyzed to identify the most significant environmental impacts and the stages of the life cycle where they occur. This information can be used to guide planning, inform product design, and support policy development.

F. *Institutional Analysis*

Institutional Analysis is a method of examining the roles, relationships, and interactions of various stakeholders, institutions (laws, bylaws, etc.), and regulations within a given system. In the context of the plastic value chain and plastic waste management system, it is helpful to identify the key actors, their responsibilities, and potential opportunities for improving the overall sustainability of plastic production, consumption, and disposal through the stakeholder analysis.

Commonly observed institutional setup are show in the upper part of Figure 3. Analyze the existing policies, regulations, and guidelines related to plastic production, consumption, and waste management [22]. This may include restrictions on single-use plastics, recycling targets, extended producer responsibility (EPR) schemes, and incentives for circular economy initiatives.

It is also necessary to assess the effectiveness of the institutional framework governing the plastic value chain and waste management system, including the coordination and collaboration among stakeholders, enforcement mechanisms, and monitoring and evaluation processes. The market dynamics affecting plastic recycling is crucial for planning the plastic waste management system.

III. Plastic Waste Treatment and Recycling Methods

Four major technologies for plastic waste treatment are reviewed as follows:

A. *Landfilling*

Landfilling of plastic waste involves the disposal of plastic wastes in landfills. While this method has been widely used for solid waste management, it presents both merits and demerits:

(1) **Merits of landfilling of plastic waste:**

Landfilling is often less expensive compared to other waste management methods such as recycling or thermal recovery (incineration). This is because it requires less complex infrastructure and technology to operate. Landfilling is also a relatively simple process, as it involves the collection, transportation, and disposal of waste in designated areas. This

simplicity makes it easy to implement, especially in regions with limited resources or technical expertise.

(2) **Demerits of landfilling of plastic waste:**

However, landfilling contributes to environmental pollution in various ways [20]. Plastics can take hundreds of years to decompose, releasing harmful chemicals into the soil and groundwater. As the amount of waste generated increases, available land for landfill sites becomes scarcer. This can lead to the need for additional land acquisition or the expansion of existing landfills, which can result in the loss of valuable ecosystems or arable land. Discarding plastics in landfills means losing the opportunity to recycle and recover valuable materials.

B. *Mechanical Recycling*

Mechanical recycling is the process of converting plastic waste into new plastic products or materials through a series of physical processes, without altering the chemical structure of the plastic [13, 20]. It is the most common and widely used method of recycling plastic waste. The mechanical recycling process typically involves the following six steps:

1) Collection and sorting: Plastic waste is collected from various sources, such as households, businesses, and recycling centers. The collected waste is then sorted by type, color, and quality, often using manual labor or automated systems, such as optical sorters or air classifiers.

2) Washing and cleaning: The sorted plastic waste is cleaned to remove contaminants, such as dirt, food residue, and labels. This step is crucial to ensure the quality of the final recycled product and may involve washing, rinsing, or other cleaning methods.

3) Size reduction: The cleaned plastic waste is processed through size reduction equipment, such as shredders, granulators, or crushers, to produce smaller plastic particles or flakes. This step facilitates further processing and improves the efficiency of subsequent processes.

4) Separation: The plastic flakes or particles are separated based on their density, size, or other properties, using methods such as air classification, flotation, or magnetic separation. This step helps to remove any remaining contaminants and ensures a uniform material stream for further processing.

5) Melting and extrusion: The plastic particles or flakes are melted and extruded through a process called compounding, which involves heating and mixing the material in an extruder. During this process, additives, such as stabilizers, pigments, or other fillers, can be added to modify the properties of the recycled plastic.

6) Pelletizing: The molten plastic is cooled and cut into small pellets, which can be used as raw material for the production of new plastic products. The pelletizing process can involve various methods, such as strand, underwater, or water ring cutting.

The recycled plastic pellets are used as feedstock for manufacturing new plastic products through various molding processes, such as injection molding, blow molding, or thermoforming.

Mechanical recycling has some limitations, such as the potential for degradation of plastic properties during processing and the difficulty in recycling mixed or contaminated plastic waste streams. However, it remains a widely used and essential method for managing plastic waste and reducing the environmental impact of plastic pollution.

C. *Thermal Recovery*

Thermal recovery of plastic waste refers to the process of extracting energy from plastic waste through various high-temperature treatments. The primary goal of thermal recovery is to convert waste plastics into valuable forms of energy, such as heat, electricity, or fuels. This method can be an alternative to landfill disposal or recycling when these options are not feasible or economically viable. The main thermal recovery processes for plastic waste include incineration, pyrolysis, and gasification, but the pyrolysis and gasification are also classified into chemical recycling.

Incineration involves burning plastic waste at high temperatures, usually between 800-1200°C, in the presence of oxygen. The process results in the generation of heat, which can be used to produce steam and drive turbines to generate electricity. Incineration can also help reduce the volume of waste by up to 90%, minimizing the need for landfill space. However, concerns exist over the potential emissions of toxic substances and greenhouse gases during the incineration process. In case of plastics with significant chlorine content, incineration causes the formation and emission of dioxins and furans, such as polychlorinated dibenzo para dioxins (PCDD) and polychlorinated dibenzo furans (PCDF) (Lazarevic et al. 2010). Modern incinerators with advanced pollution control systems can minimize these emissions and comply with stringent environmental standards.

Thermal recovery methods has its advantages and limitations, and their environmental and economic viability depends on factors such as waste composition, energy prices, and the availability of recycling or disposal alternatives [20].

D. *Chemical Recycling*

Chemical recycling is an advanced recycling method that breaks down plastic waste into its basic chemical building blocks, which can then be used to produce new plastic materials or other chemicals. Unlike mechanical recycling, which primarily involves the physical processing of plastic waste (e.g., shredding, melting, and molding), chemical recycling involves a series of chemical reactions that convert plastic polymers back into their constituent monomers or other valuable chemicals [13]. The following three methods are major chemical recycling technologies:

(D-1) Pyrolysis: Pyrolysis is a thermal process that decomposes plastic waste in the absence of oxygen at elevated temperatures, typically between 400-800°C. The process converts plastic waste into a mixture of gases, liquids (pyrolysis oil), and solid residues (char). Pyrolysis oil can be further refined and used as a feedstock for producing new plastics, chemicals, or fuels, while the gases can be utilized for energy production. Pyrolysis is considered a form of chemical recycling, but it can also be classified as a thermal recovery process due to its focus on energy recovery.

(D-2) Gasification: Similar to pyrolysis, gasification involves heating plastic waste at high temperatures in the presence of limited oxygen or other reactive gases. This process converts plastic waste into a mixture of carbon monoxide and hydrogen, known as syngas, which can be used as a feedstock for producing chemicals, fuels, or electricity. Gasification offers potential advantages over incineration, such as lower emissions and higher energy conversion efficiencies.

(D-3) Depolymerization: This process involves breaking down plastic polymers into their constituent monomers using heat, pressure, and/or chemical catalysts. The recovered monomers can then be purified and used to produce new plastic materials. This process is particularly suitable for certain types of plastics, such as polyesters (e.g., PET) and polyamides (e.g., nylon).

Chemical recycling offers several advantages over traditional mechanical recycling, such as the ability to process mixed or contaminated plastic waste streams and produce high-quality recycled materials.

IV. Capacity Development in Plastic Waste Management

Capacity development in plastic waste management refers to the process of enhancing the ability of individuals, organizations, and communities to effectively manage plastic waste. This involves the development of knowledge, skills, technology, and infrastructure to reduce, reuse, and recycle plastic waste, ultimately minimizing its impact on the environment and human health. The key aspects of capacity development in plastic waste management are as follows:

Develop and implement comprehensive policies, regulations, and guidelines on plastic waste management. Ensure that these frameworks are aligned with international best practices and tailored to local conditions. Establishing and enforcing robust policies and regulations can help promote the reduction, reuse, and recycling of plastic waste. This may include imposing restrictions on single-use plastics (SUPs), incentivizing recycling, and implementing extended producer responsibility (EPR) schemes, where manufacturers are held accountable for the waste generated by their products.

Increasing public awareness of the environmental and health risks associated with plastic waste is crucial. This can be achieved through educational programs, campaigns, and

social media platforms to inform people about the importance of proper waste management, waste reduction, and recycling.

Providing training and workshops to plastic waste management personnel, community leaders, and other stakeholders can help build the necessary skills and knowledge required to handle plastic waste efficiently. This includes training in plastic waste segregation, reuse and recycling techniques, and monitoring of plastic pollution.

Investing in the establishment of proper solid waste management facilities, such as waste collection/transport equipment, material recovery facilities (MRF), recycling centers, and WtE plants, can help in the efficient management of plastic waste. This requires financial support from governments, private sectors, and international organizations.

Under the given conditions, developing techniques and adopting technologies for plastic waste management are crucial. This includes advancements in system design, 3R practices, recycling processes, WtE conversion technologies, and development of substitute materials for plastics that are more easily recyclable or biodegradable.

Encouraging collaboration among stakeholders can help in sharing knowledge, resources, and best practices to address plastic waste management challenges more effectively. Facilitate regular communication and coordination among different government agencies and departments responsible for plastic waste management. This can help to harmonize policies, streamline processes, and ensure efficient use of resources.

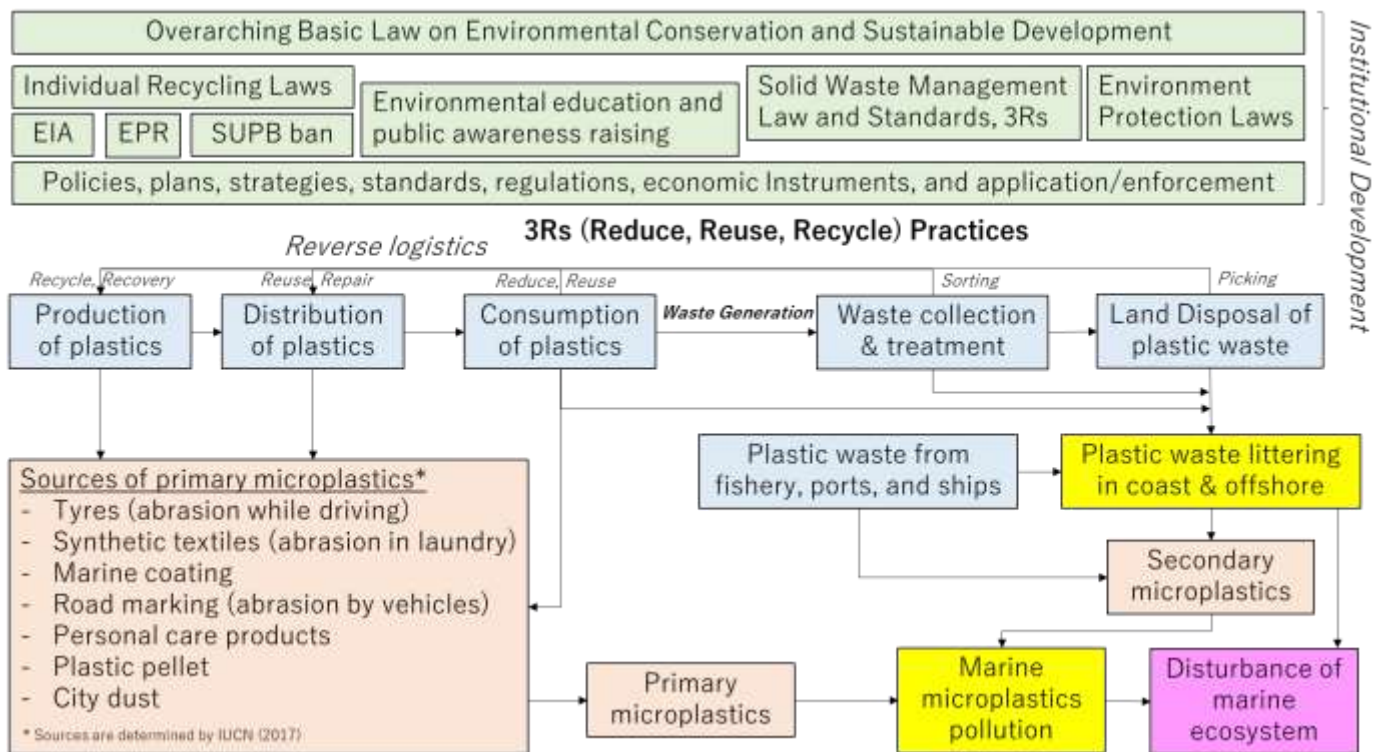


Figure 4. Framework of plastic value chain, plastic waste management, and plastic/microplastic pollutions.

V. Conclusions

Fig. 4 summarized the framework of plastic value chain, plastic waste management, plastic waste pollutions, and relevant institutional setting. For enhancing the plastic waste management system, technical assistance projects need a comprehensive approach that addresses various aspects of the issue, from production of plastic to plastic waste disposal and its environmental loads. It can be concluded that the following points are crucial for technical assistance issues to promote an effective plastic waste management system:

It is necessary to develop and implement strong policies and regulations related to plastic waste management, including bans on single-use plastics (SUPs), extended producer responsibility (EPR) policies, and regulations governing waste collection and disposal.

Plastic waste reduction/minimization should be continuously encouraged through public awareness raising campaigns and educational initiatives that promote avoiding plastic waste generation and the responsible use of plastic products such as using reusable bags, containers, and packaging. Waste segregation at the source can promote to ensure that plastic waste is separated from other waste materials, making it easier to process and recycle.

Well-organized investment is required in the development of plastic waste management infrastructure, including collection and transportation systems, recycling facilities, and WtE plants. This will help ensure that plastic waste is processed and disposed of properly. A promotion of research and development is also necessary in plastic recycling technologies to create more efficient and cost-effective methods for processing plastic waste under given conditions.

It is expected to foster collaboration between government agencies, research institutes, private companies, NGOs, and local communities to leverage resources, expertise, and innovative solutions for plastic waste management.

Governments need to encourage producers to take responsibility for the entire life cycle of their plastic products by introducing EPR policies. This may involve product design improvements, setting up take-back programs, or financing recycling infrastructure.

By implementing these analyses, assessments, and strategies in technical assistance projects, the partner (recipient) countries can enhance plastic waste management, reduce plastic pollution, and contribute to environmental sustainability and public health.

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